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THE METHOD OF CORRELATION EQUATIONS IN  
THE EVALUATION OF STRUCTURAL STRENGTH  
AND RELIABILITY

M. Ya. Shashin, et al

Foreign Technology Division  
Wright-Patterson Air Force Base, Ohio

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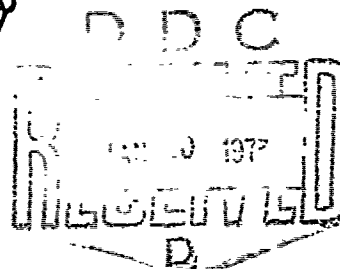
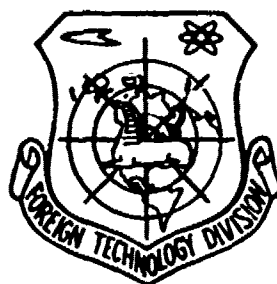
## FOREIGN TECHNOLOGY DIVISION



THE METHOD OF CORRELATION EQUATIONS IN THE EVALUATION  
OF STRUCTURAL STRENGTH AND RELIABILITY

by

M. Ya. Shashin, Yu. D. Zheleznyakov,  
and S. L. Manevich



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Cromensil Steel						
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Metal Cracking						
Rupture Strength						
Steel Sheet						
Statistic Analysis						
Polymethylmethacrylate						

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By: M. Ya. Shashin, Yu. D. Zheleznyakov, and  
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# U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

\* ye initially, after vowels, and after ъ, ь; e elsewhere.  
 When written as ѐ in Russian, transliterate as yě or ě.  
 The use of diacritical marks is preferred, but such marks  
 may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH  
DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	$\operatorname{sech}^{-1}$
arc csch	$\operatorname{csch}^{-1}$
rot	curl
lg	log

# THE METHOD OF CORRELATION EQUATIONS IN THE EVALUATION OF STRUCTURAL STRENGTH AND RELIABILITY

Doctor of Technical Sciences Prof.  
M. Ya. Shashin, Candidate of Tech-  
nical Sciences Yu. D. Zheleznyakov,  
and Engineer S. L. Manevich

(Higher Aviation College of  
Civil Aviation)

A great deal of experimental material (cyclic strength of Chromansil steel, growth of fatigue cracks in marine sheet steel, the persistent strength of polymethylmethacrylate) is used to demonstrate the effectiveness of the application of statistical processing on the basis of a compilation of correlation equations, the parameters of which become stable in the case of the selection of  $\geq 20$  samples in the selection, which facilitates the determination of prediction reliability.

Numerous test data show that the inclined branches on the fatigue curves of metals and the curves of prolonged strength and creep of polymers are straight lines in double logarithmic or in semilogarithmic coordinates [1, 2]. It has been established experimentally that the dependence of the length of the fatigue crack on durability in logarithmic coordinates for marine sheet steel is also linear on the very prolonged middle stage of development [3].



In all these cases during the determination of the prediction reliability the statistical processing of experimental data based on the compilation of equations of regression is very convenient and effective [4]. The scattering of experimental data and the determination of reliability in this case are evaluated with the help of the degree of individual scattering  $S_{Nr}$  and the mean square deviation of the index of slant  $S_m$  [4]. The stated statistical evaluations become stable when there are more than 16 test samples.

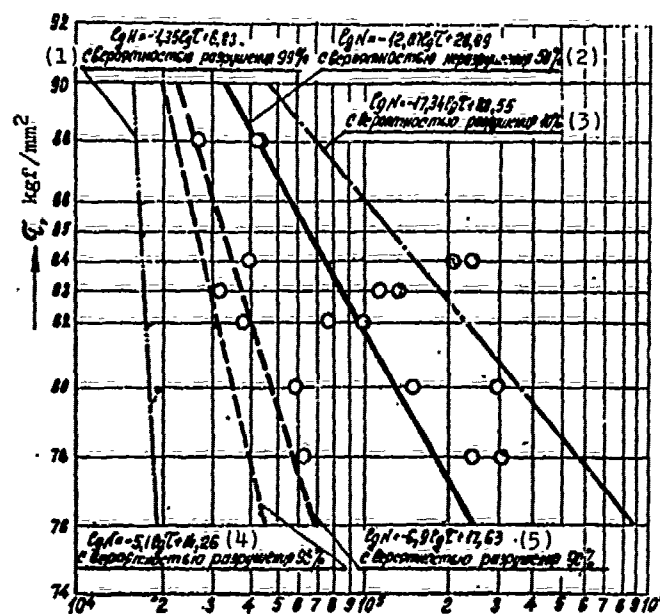


Fig. 1. Results of testing the pulsating expansion of flat samples made from 30KhGSA steel (18 samples selected from a total of 153).  
KEY: (1) with a 99% probability of destruction; (2) with a 50% probability of nondestruction; (3) with a 10% probability of destruction; (4) with a 95% probability of destruction; (5) with a 90% probability of destruction.

Actually in Fig. 1 the results are given from the processing of a selection of 18 pieces obtained during the testing of pulsating expansion of 153 pieces of flat samples made from 30KhGS steel. The lines of regression possess satisfactory convergence with the logarithmically normal law of distribution. To the left of the straight lines with a nondestruction probability of 95 and 99%

experimental points are absent. To the left of the straight line for 90% the destruction of only two samples out of 18 takes place. Consequently the actual probability of nondestruction  $P_2 = 1 - 2/19 \approx 0.90$  coincided with the results of the proposed processing of experimental data.

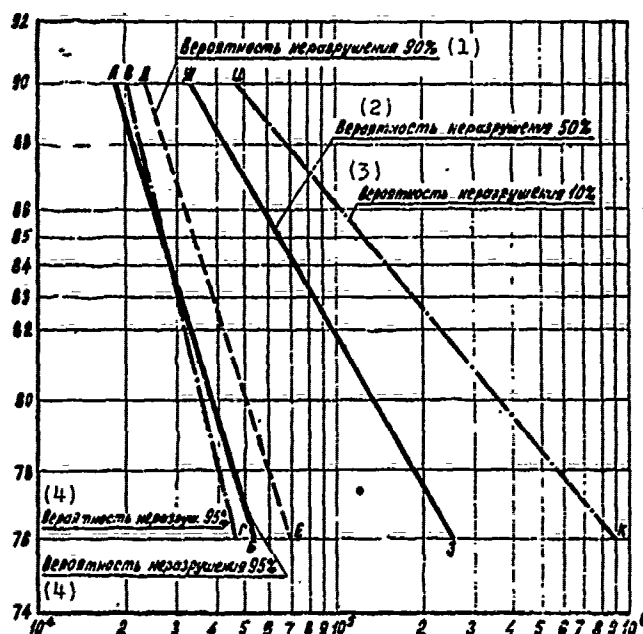


Fig. 2. Comparison of the statistical processing of the results of testing a selection of 18 samples (BF, DE, ЖЗ, ИИ) with the results of processing the entire aggregate AB.

KEY: (1) 90% probability of nondestruction; (2) 50% probability of nondestruction; (3) 10% probability of nondestruction; (4) 95% probability of nondestruction.

Figure 2 shows the results of the statistical processing of another selection of the same volume. The straight lines ИИ ЖЗ ДЕ and BF are straight lines of regression of the selection for the probabilities of nondestruction of 10, 50, 90, and 95% respectively. Straight line AB is the line of regression for the entire aggregate with a probability of nondestruction of 95%. The closeness of straight lines AB and BF again confirms the possibility of the reliable evaluation of scattering and, consequently, the reliability

based on the results of the methods shown above for the statistical processing of a selection made up of 16-20 tests.

The analogous conclusion is made during the processing of the results of tests of the pulsating torsion of samples and torsions made from spring steel [5].

#### Regularities in the Growth of Fatigue Cracks During the Alternating Sign Bending of Flat Samples

The durability of constructions and parts is a combination of a number of cycles necessary for the origin and distribution of fatigue cracks. At the present time there are still no reliable methods for the indication of damage during the process of development of submicroscopic cracks. However, after the appearance of a visible macrocrack it is possible to fix reliably any change in its parameters during the process of cyclic loading. Tests showed that the number of cycles from the moment of the emergence of a visible fatigue crack and up to destruction comprises 88-95% of the overall durability.

During the development of a fatigue crack 3 stages of growth are observed. During the first stage an increase in rate with the development of the crack is characteristic. In the second stage the rate of growth is stabilized and remains constant in the range of lengths of 0.15-0.60 from the width of the sample. This stage of stable development of the crack is the longest and occupies around 80% of the time from the moment of emergence of a visible crack up to the destruction of the sample. In the third stage the rate of growth increases rapidly, reaching values of one-two orders higher than in the second stage. The duration of the first and third stages is comparatively small and the magnitude of durability depends mainly on the rate of growth in the second stage.

Consequently in this stage during the study of the dependence of length  $l$  and rate of growth of the crack on the number of cycles

the method of compilation of correlation equations is the most expedient. Figure 3 shows the graphs of probable lines of regression 2 and 5 between the boundaries of confidence intervals 1 and 3, 4 and 6 (conference reliability = 80%).

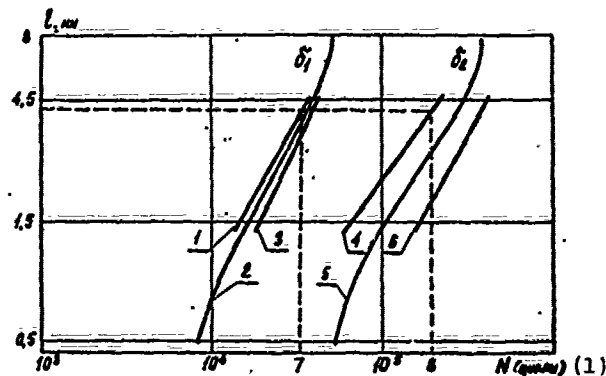


Fig. 3. Dependence of the length of a crack  $l$  on  $N$  (SKhL-4,  $\sigma_1 = 40 \text{ kgf/mm}^2$ ,  $\sigma_2 = 30$

$\text{kgf/mm}^2$ ) and the arrangement for the evaluation of reliability: 2, 5 - average lines of regression (for  $\sigma_1$  and  $\sigma_2$ ); 1, 3, 4, 6 - boundaries of confidence intervals; 7, 8 - safe number of cycles at which  $l \leq l_{kp}$ .

KEY: (1) (cycles).

With the help of such graphs it is possible to evaluate reliability or to determine the guaranteed probability that at a certain number of cycles the length of a crack will not exceed a certain critical value (Fig. 3). The principle of the determination of a guaranteed resource for various planned tasks, the selection of permissible stress  $\sigma$  is shown by points 7, 8. Point 7 characterizes the magnitude of the guaranteed resource, corresponding to a high probability that the logarithm for the length of the crack  $\lg l$  will not exceed a permissible value at assigned rigid stress conditions  $\sigma_1 > \sigma_2$ . Point 8 answers the guaranteed resource at milder conditions  $\sigma_2$ . Straight line 2 is the line of regression characterizing the growth of the crack at  $\sigma_1$ . Straight lines 1 and 3 are the boundaries of the confidence interval, and straight line 5 characterizes the growth of the crack at  $\sigma_2$  (boundaries of

confidence interval straight lines 4 and 6). The magnitude of confidence intervals is proportional to the degrees of individual scattering.

A comparison of the results of statistical processing of selections with a various number of experimental data again showed that also in this case, just as during the study of the cyclic strength of metals, the statistical evaluations of correlation equations become stable at a number of samples  $n \approx 20$ . The confidence intervals differ little from the evaluations of Student, and the grouping of experimental data corresponds to normal distribution.

#### Method for the Determination of the Parameters of Creep and Prolonged Strength of Polymethylmethacrylate

The data from flight and natural bench tests of elements for fitting aircraft with glass were used for determining the spectrum of loads under operational conditions and for developing a program of static and repeated loading of samples under laboratory conditions. For various levels of loading in the case of statistical processing [4] regression equations of the following type are obtained

$$\delta = A + B\bar{t}$$

where  $\bar{t} = t/t_p$  ( $t_p$  - static durability at a given load), coefficient  $B$  - statistical parameter,  $B = r \frac{S_\delta}{S_t}$ ,  $S_\delta$  - mean square deviation of relative deformation of creep,  $S_t$  - mean square deviation of relative guaranteed resistance based on static longevity,  $r$  - coefficient of correlation.

In the case of ruggedization of the guaranteed probability the value of  $B$  is changed, which causes a change in the slant of the straight line of the upper boundary of the confidence interval

in comparison with the slant of the straight line which is the middle line of regression for the assigned stress.

The principle for the determination of the guaranteed resource for various projected assignments (selection of the permissible stress  $\sigma$ ) is analogous to that shown in Fig. 3. The magnitude of confidence intervals is proportional to the degrees of individual scattering. For finding the guaranteed resource in the case of an operational spectrum of loads the following type of correlation dependences of prolonged strength are determined

$$\sigma = C - D \lg t$$

in the case of static and repeated loading, and also the conditions of damage and strengthening are revealed, and on the basis of these the conditions of equivalency in the case of static and variable loads are compiled.

A comparison of the results of the statistical processing of selections with a various number of experimental data showed that in this case, just as in the study of cyclic strength of metals,  $n \approx 20$ . Confidence intervals differ little from the evaluations of Student and the grouping of experimental data corresponds to normal distribution.

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